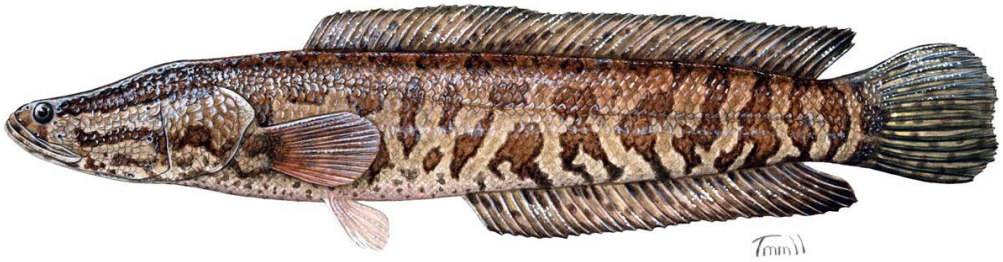
National Control and Management Plan for the Northern Snakehead (*Channa argus*)



Drawing by: Susan Trammell

Submitted to the Department of Interior
Prepared by the Northern Snakehead Working Group

Working Group Members

Steve Chaconas, National Bass Guide Service
Melissa Cohen, New York Department of Environmental Conservation
Don Cosden, Maryland Department of Natural Resources
Walter R. Courtenay, U.S. Geological Survey
Jim Cummins, Interstate Commission on the Potomac River Basin
Ken Endress, U.S. Fish and Wildlife Service
Jim Gilmore, New York Department of Environmental Conservation
Richard Horwitz, Academy of Natural Sciences, Philadelphia, Pennsylvania
Cindy Kolar, U.S. Geological Survey
Bob Lunsford, Maryland Department of Natural Resources
Steve Minkkinen, Coordinator, U.S. Fish and Wildlife Service
John Odenkirk, Virginia Game and Inland Fisheries
Tom Orrell, Smithsonian Institution
Brian Richardson, Maryland Department of Natural Resources
Jon Siemien, D.C. Fisheries and Wildlife
Julie Slacum, U.S. Fish and Wildlife Service

Executive Summary

The introduction of non-native northern snakeheads (*Channa argus*) into waterways of the United States has received a great deal of media, public, and political attention. Unfortunately, this awareness has not served to prevent further spread of northern snakeheads into American waterways. The northern snakehead is a popular food fish in Asia that was imported into the U.S. for the live-food fish market until 2002, when the U.S. Fish and Wildlife Service (USFWS) prohibited importation and interstate transport under the Lacey Act, 18 U.S.C. 42.

Prior to 2002, the occurrence of northern snakeheads in the United States was limited and consisted of low numbers in California, Florida, Massachusetts, and North Carolina. In 2002, a self-sustaining population was discovered and later eradicated in a small pond in Crofton Maryland. Northern snakeheads were discovered in the tidal freshwater Potomac River in the vicinity of Mount Vernon in May 2004. The population has increased rapidly in range and abundance. By 2011 the fish occured in the main stem and tributaries from Great Falls downstream to the mouth of the river and recently 2 snakeheads have been captured in the Chesapeake Bay near St. Jerome's Creek north of the mouth of the Potomac River. It was initially thought that higher salinity in the lower river and Chesapeake Bay would prevent snakeheads from escaping out of the Potomac River into other tributaries of the Chesapeake Bay. Now this assumption does not appear to be guaranteed. The falls at Great Falls currently block upstream migration of snakeheads. There is concern that the C & O canal could allow these fish to bypass the falls. Other populations of Northern snakeheads have also been discovered. In July 2004, northern snakeheads also were discovered in Meadow Lake in Philadelphia County, Pennsylvania. There have been confirmed reports of snakeheads escaping from the ponds into the Schuylkill River and Delaware River. The status of this population is unknown. During 2008 populations of snakeheads were discovered in Piney Creek in Arkansas which is a tributary to the Mississippi River. The same year another population was found in Catlin Creek in New York which is a tributary to the Hudson River. In the last two occurrences aggressive control measures were conducted to try to eradicate the populations before they could escape into these major river systems. It is unclear if these control measures have completely eradicated the populations.

Congress requested that the USFWS address concerns about the introduction of northern snakeheads. Senate report 108-341, Department of the Interior and Related Agencies Appropriations Bill (2006) of the 109th Congress states, "the Committee is concerned by the recent discoveries of northern snakehead in the Potomac River and its potential impact on native fish populations through predation, food and habitat competition, or the introduction of diseases and parasites. The Committee directs the USFWS to submit a report to Congress on steps the Agency is taking to identify, contain, and eradicate the species."

In response to this Congressional mandate, the USFWS assembled a Northern Snakehead Working Group (NSWG) to provide input on the development of a Northern Snakehead Control and Management Plan (NSCMP). This NSCMP was developed with the input of

the NSWG and other northern snakehead experts to guide the USFWS and other interested parties in managing and controlling existing populations, and preventing the spread and introduction of this species into additional areas of the United States. The NSWG agreed on goals and objectives of the NSCMP as well as management actions that achieve the stated goals and objectives.

The goal of this NSCMP is:
Use sound science and management to prevent future introduction of northern snakeheads into new areas, minimize impacts in areas where they are already established, and recommend effective eradication methods where appropriate.
Objectives:

1. Prevent new introductions of northern snakehead within the U.S. and limit the spread of established populations into new areas.
2. Detect and rapidly respond to northern snakehead introductions in U.S. waters.
3. Wherever possible, contain and eradicate newly discovered populations of northern snakehead.
4. Provide long-term adaptive management and mitigate impacts of northern snakehead in U.S. waters where eradication is not possible.
5. Conduct research to better understand impacts of northern snakeheads on native aquatic organisms.
6. Develop outreach tools to prevent new introductions of northern snakeheads within the U.S. and control the spread of established populations into new areas.
7. Review and assess progress of the National Management Plan.

Table of Contents

Figures and Tables

Figures

Tables

Photos

1. Purpose of this Management Plan

The purpose of this Northern Snakehead Control and Management Plan (NSCMP) is to guide the U.S. Fish and Wildlife Service (USFWS) and other interested parties in managing invasive northern snakeheads already established in U.S. waters as well as prevent the further spread and introduction of this fish into American waterways.

Northern snakeheads were a popular food fish imported into the U.S. for the live-food fish market until 2002 when the USFWS prohibited importation and interstate transport under the Lacey Act. Prior to 2002, the occurrence of northern snakeheads in the United States was limited and consisted of low numbers in California, Florida, Massachusetts, and North Carolina. In 2002, a self-sustaining population was discovered and later eradicated in a small pond in Crofton Maryland. Northern snakeheads were discovered in the main-stem tidal freshwater Potomac River in the vicinity of Mount Vernon in May 2004. The population has increased rapidly in range and abundance. These fish now occur in the main stem and tributaries from Great Falls downstream to the mouth of the river (Fig. 3). During June of 2010 a snakehead was captured in a pound net in the Chesapeake Bay near St. Jerome's Creek north of the mouth of the Potomac River. Another snakehead was caught by an angler in St. Jerome's Creek on May 4, 2011. It was initially thought that higher salinity in the lower river and Chesapeake Bay would prevent snakeheads from escaping into other tributaries of the Chesapeake Bay. Now this assumption does not appear to be certain. The falls at Great Falls are blocking the upstream movement of snakeheads. There is concern that the C & O canal could allow these fish to bypass the falls. Other populations of Northern snakeheads have also been discovered. In July 2004, northern snakeheads also were discovered in Meadow Lake in Philadelphia County, Pennsylvania. There have been confirmed reports of snakeheads escaping from the ponds into the Schuylkill River and Delaware River. The current status of this population is unknown. During 2008 populations of snakeheads were discovered in Piney Creek in Arkansas which is a tributary to the Mississippi River. The same year another population was found in Catlin Creek in New York which is a tributary to the Hudson River. In the last two occurrences aggressive control measures were conducted to try to eradicate the populations before they could escape into these major river systems. It is unclear if these control measures have completely eradicated these populations. There have also been sporadic single occurrences of northern snakeheads that appear to be the result of releases of single fish but there is no indication of reproducing populations. Reproducing populations of snakeheads appear to increase rapidly so they are easy to detect.

Congress requested that the USFWS address concerns about the introduction of northern snakeheads. Senate report 108-341, Department of the Interior and Related Agencies Appropriations Bill of the 109th Congress states, "the Committee is concerned by the recent discoveries of northern snakehead in the Potomac River and its potential impact on native fish populations through predation, food and habitat competition, or the introduction of diseases and parasites. The Committee directs the U.S. Fish and Wildlife

Service to submit a report to Congress on steps the Agency is taking to identify, contain, and eradicate the species."

In response to this Congressional mandate, the USFWS assembled a Northern Snakehead Working Group (NSWG) in 2006 to provide input on the development of a NSCMP. The intent of the NSCMP is to identify action items to guide agency activities and funding priorities in addition to focus efforts of stakeholders, and Non-Governmental Organizations. The plan's focus is on specific control priority action items needed in the Potomac River and Northeast region as well as general prevention, early detection and rapid response, control, research, and education and outreach priorities for the rest of the nation, should additional northern snakehead populations be discovered.

On February 15-16, 2006 the NSWG met to discuss the goals, objectives, and priority actions of the NSCMP to manage northern snakehead in U.S. waters. A draft report was completed in February of 2007. An update tot the report was completed in March of 2011.

The goal of this NSCMP is:
Use sound science and management to prevent future introduction of northern snakeheads into new areas and minimize impacts in areas where they are already established and recommend effective eradication methods where appropriate.
Objectives:

1. Prevent new introductions of northern snakeheads within the U.S. and control the spread of established populations into new areas.
2. Detect and rapidly respond to northern snakehead introductions in U.S. waters.
3. Wherever possible, contain and eradicate newly discovered populations of northern snakeheads.
4. Provide long-term adaptive management and mitigate impacts of northern snakeheads in U.S. waters where eradication is not possible.
5. Conduct research to better understand impacts of northern snakeheads on native aquatic organisms.
6. Develop outreach tools to prevent new introductions of northern snakeheads within the U.S. and control the spread of established populations into new areas.
7. Review and assess progress of the National Management Plan.

2. Biology and Ecology of the Northern Snakehead

Identification and Life History

Snakeheads (family *Channidae*) are air breathing freshwater fishes containing two genera, *Channa*, native to Asia, Malaysia, and Indonesia, and *Parachanna*, endemic to tropical Africa. The northern snakehead (*Channa argus*) is native to the rivers and estuaries of China, Russia, and Korea (Courtenay and Williams, 2004). This species was purposefully established in Japan in the early 1900s (Okada, 1960, cited by Courtenay and Williams, 2004), however, its subsequent establishment in ponds, rivers, and reservoirs of Kazakhstan, Turkmenistan, and Uzbekistan in the early 1960s may have been accidental, with snakeheads mixed with shipments of Asian carps (Courtenay and Williams, 2004). Within its native (Berg, 1965, cited by Courtenay and Williams, 2004)

and introduced range, with the exception of Japan, it is considered a desirable and sought after food fish (Baltz, 1991; Dukravets, 1992; FAO, 1994; Okado, 1960; cited by Courtenay and Williams, 2004). In China, it is the most important snakehead species cultured (Courtenay and Williams, 2004) where it is grown in ponds, rice paddies, and reservoirs (Atkinson, 1977; Sifa and Senlin, 1995; Liu et al., 1998; cited by Courtenay and Williams, 2004).

In major cities such as Calcutta, Bangkok, Singapore, and Hong Kong, northern snakeheads are a specialty food item, available alive in aquaria for customer selection at finer restaurants. They also provide easily caught food for less affluent people (Wee, 1982; cited by Courtenay and Williams, 2004). Northern snakeheads are usually killed just prior to preparation and cooked a variety of ways. They can be cooked whole or prepared as filets or steaks, fried or steamed, or put in soups (Courtenay and Williams, 2004). Wee (1982) and Balzer et al. (2002), cited by Courtenay and Williams (2004), documented that excess catches in Thailand and Cambodia are often dried for storage and future use. Some cultures believe that because snakeheads can remain alive outside of water for periods of time, the fish have healing properties, which makes them prized as food for people that are ill. In such situations, the fish are killed just before cooking because of the belief that the healing properties will be lost if the fish are killed sooner (Courtenay and Williams, 2004).

Northern snakeheads are most readily identified by long dorsal and anal fins; pelvic fins located beneath the pectorals; a truncate caudal fin; and a large mouth reaching far beyond the eye with some large canine-like teeth on the upper and lower jaws. Adult northern snakeheads are golden tan to pale brown in color with series of dark, irregular patches on the sides and saddle-like blotches across the back interrupted by the dorsal fin. Coloration of juveniles is similar to the adults (Courtenay and Williams, 2004). Northern snakeheads can grow up to 85 cm in length (Okada, 1960, cited by Courtenay and Williams, 2004) however, in Russia there have been reports of captured specimens reaching 1.5 m total length (Courtenay and Williams, 2004).

Photo 1: A northern snakehead captured in Pennsylvania. Photo by Joe Perillo, Philadelphia Water Department.

Northern snakeheads reach sexual maturity at 2 to 3 years of age and approximately 30-35 cm in length. Females produce eggs 1 to 5 times per year and release 22,000-51,000 eggs per spawn (Frank, 1970; Nikol'skiy, 1956; cited by Courtenay and Williams, 2004). Dukravets and Machulin (1978), cited by Courtenay and Williams (2004), documented fecundity rates that ranged from 28,600-115,000 for northern snakeheads introduced to the Syr Dar'ya basin of Turkmenistan/Uzbekistan. Their eggs float and take approximately 28 hours to hatch at 31^{o}C and 45 hours at 25^{o}C. At lower temperatures the eggs take much longer to hatch. Parents guard the young in a nest until yolk absorption is complete at approximately 8 mm in length. Young northern snakeheads eat zooplankton. At a length of about 18 mm the young begin feeding on small crustaceans and fish larvae (Courtenay and Williams, 2004). Adults feed on fishes, frogs, crustaceans, and aquatic insects (Courtenay and Williams, 2004). Okado (1960), cited by Courtenay and Williams (2004), reported that this species is a voracious feeder. In the Syr Dar'ya Basin, Dukravets and Machulin (1978), cited by Courtenay and Williams (2004), reported that northern snakeheads fed on 17 species of fish, including juveniles and fish up to 33 percent of the predator's body length. Other food items included crayfish, dragonfly larvae, beetles, and frogs, as well as plant material that are probably ingested with the prey. In the Amu Dar'ya basin, Guseva and Zholdasova (1986), cited by Courtenay and Williams (2004), reported that northern snakeheads fed on zooplankton in their first month of life. At a length of 4 mm they begin to feed on fish and then at 13-15 cm, fishes comprise 64-70% of the diet. Juveniles up to 30 cm feed almost exclusively on fish. Food items observed in northern snakeheads (n=219) collected from the Potomac River between 2004 and 2006, consisted mostly of banded killifish (*Fundulus diaphanous*), white perch (*Morone americana*), bluegill (*Lepomis macrochirus*) and pumpkinseed sunfish (*Lepomis gibbosus*). (Figure 1, Odenkirk and Owens, 2007).

Common name	Scientific name	Freq.
banded killifish	*Fundulus diaphanus*	27%
white perch	*Morone americana*	5%
pumpkinseed sunfish	*Lepomis gibbosus*	5%
bluegill	*L. macrochirus*	5%
goldfish	*Carassius auratus*	2%
gizzard shad	*Dorosoma cepedianum*	1%
American eel	*Anguilla rostrata*	1%
yellow perch	*Perca flavescens*	1%
largemouth bass	*Micropterus salmoides*	1%
spottail shiner	*Notropis hudsonias*	1%
eastern silvery minnow	*Hybognathus regius*	<1%
mummichog	*F. heteroclitus*	<1%
channel catfish	*Ictalurus punctatus*	<1%
green sunfish	*L. cyanellus*	<1%
tessellated darter	*Etheostoma olmstedi*	<1%
frog		<1%
crayfish		<1%

Figure 1. Frequency of occurrence (Freq.) of identifiable food items found in gut contents of 219 northern snakeheads. (Odenkirk and Owens, 2007)

In the Amu Dar'ya basin, northern snakeheads only feed from late March to October with 45% of its annual food consumption completed by May and another 46% of annual consumption occurring in June and July**.** Juvenile northern snakeheads feed in schools, with most of the activity during early evening and again in early morning, usually in vegetation close to shore (Courtenay and Williams, 2004).

Habitat and Environmental Tolerances

Northern snakeheads prefer stagnant shallow ponds or swamps with mud substrate and vegetation. They can also be found in slow muddy streams (Okada, 1960; cited by Courtenay and Williams, 2004) and in canals, reservoirs, lakes, and rivers (Dukravets and Machulin, 1978; Dukravets, 1992; cited by Courtenay and Williams, 2004). In the Potomac River, northern snakeheads are found in shallow water with floating and emergent vegetation (Odenkirk and Owens, 2005; Lapointe et al., 2010). Northern snakeheads have a broad temperature tolerance of 0 to 31°C (Okada, 1960; Dukravets and Machulin, 1978; cited by Courtenay and Williams, 2004). The species is an obligate airbreather; therefore, survival in low oxygen waters is possible (Courtenay and Williams, 2004). During cold temperatures, the northern snakehead has a reduced metabolism and oxygen demand, which allows them to survive under ice (Frank, 1970; cited by Courtenay and Williams, 2004). The USFWS and Maryland Department of Natural Resources (MDNR) conducted several experiments at their Manning Hatchery to examine the salinity tolerances of northern snakehead. Replicate treatments were conducted that included holding fish at static concentrations of 0, 3, and 10 parts per thousand salinity (ppt). A fourth treatment increased salinity by 1 ppt per day until mortality occurred. Water quality was monitored during the trials and tanks were aerated to maintain suitable oxygen levels. Live fish were also introduced to provide forage. Water was periodically exchanged to maintain water quality. Treatments lasted up to 48 days. Water temperatures in the tanks influenced the tolerance of snakeheads to salinity. At temperatures between 20-24 C, exposure to 10 ppt induced mortality in 10-12 days and the upper level of tolerance ranged between 15 and 18 ppt. In trials that were conducted at lower temperatures that ranged between 15-20 C, snakeheads exhibited increased tolerance to salinity. In these trials individuals held at 10 ppt exhibited indefinite (> 30 days) survival and in many cases continued to actively forage. However the upper tolerance level remained at 18 ppt (personal communication, Steve Minkkinen, USFWS). The capture of a snakehead in a pound net in the bay near St. Jerome's Creek during May of 2010 confirms that northern snakehead can tolerate salinity and will venture into saline areas. Surface salinities at the mouth of the Potomac ranged between 10 and 12 ppt during that time. Snakeheads have also colonized Potomac River tributaries down to the mouth of the river which required them swimming through the lower river, where salinities typically range from 6-20 ppt. The salt wedge in the lower Potomac River may not prevent the spread of snakeheads into the Chesapeake Bay and other tributaries.

The northern snakehead, because of its torpedo-shaped body, has limited ability to move onto land except as young, and only during flood conditions (Courtenay and Williams, 2004). At the pond in Crofton, Maryland, the Maryland Department of Natural Resources noticed that when juvenile northern snakehead jumped out of buckets, they did not "crawl away" and eventually died (personal communication, Don Cosden, Maryland Department of Natural Resources).

3. Introduction of Northern Snakeheads into U.S. waters

Northern snakeheads likely arrived in U.S. waters by importation for the live food fish market. For the last two decades, snakeheads have been imported to the U.S. for sale in some ethnic markets that sell live food fish and some restaurants that hold fish live in aquaria for customer selection. Northern snakeheads likely comprised the greatest volume and weight of live snakeheads imported into the U.S. until 2001 (Courtenay and Williams, 2004). Prior to 2002, importation and sale of the species was legal in most states, but there were violations in at least six states where possession and sale of live snakeheads was illegal. Although import records are incomplete and not detailed it is evident that from 1997 to 2002, imports of live snakeheads into the U.S. increased (Table 1) and that China was the biggest exporter of live snakeheads (Table 2).

Since the addition of the snakehead family under the prohibitions of the Lacey Act in 2002, the USFWS, Office of Law Enforcement, has continued to seize illegal shipments of snakeheads imported to the United States. As recently as February 2011, a shipment of over 350 Chinese snakehead (*Channa asiatica*) was seized at an airportin New York (USFWS 2011).

Table 1. U.S. importations of live snakeheads (*Channidae*, all species) during 1997-2002 (adapted from Courtenay and Williams, 2004).

Year	Number of individuals	Total mass (kilograms)	Total declared value (US dollars, individuals and weight combined)
1997	372	892	5,085
1998	1,488	1,883	12,632
1999	6,044	8,512	27,718
2000	8,650	9,240	39,990
2001	18,991	1,681	21,185
2002	15,688	--	26,077
Totals	51,233	22,208	$132,687

Table 2. Origin of snakehead shipments (*Channidae*, all species) for 1997-2002; records for 2002 extend through May 31. (Adapted from Courtenay and Williams, 2004).

Country	Number of individuals	Total mass (kilograms)	Total declared value (US dollars, individuals and weight combined)
China	48,533	20,323	125,295
Hong Kong	2	--	50
India	572	--	1,498
Indonesia	300	--	96
Nigeria	970	--	659
Switzerland	50	--	100
Thailand	1,084	--	1,420
United States	25	--	38
Vietnam	1,079	1,435	4,265

Northern snakeheads are the most widely cultured snakehead species in China and have been available for sale in Asian live food fish markets in New York and St. Louis, Missouri (Courtenay and Williams, 2004). Courtenay and Williams (2004) obtained live specimens from fish markets in New York; Houston, Texas; Pembroke Pines, Florida; and Orlando, Florida. Prior to the prohibitions under the Lacey Act, live snakeheads were purported to have been available in live fish food markets and restaurants in Washington D.C., northern Virginia, and Maryland.

The first report of this species in the U.S. was in Silverwood Lake in California on October 22, 1997. The fish was collected by California Department of Fish and Game personnel by electrofishing (Courtenay and Williams, 2004). It is unknown whether the 71 cm specimen was purposefully released in the lake or whether it arrived through the California aqueduct (Figure 2).

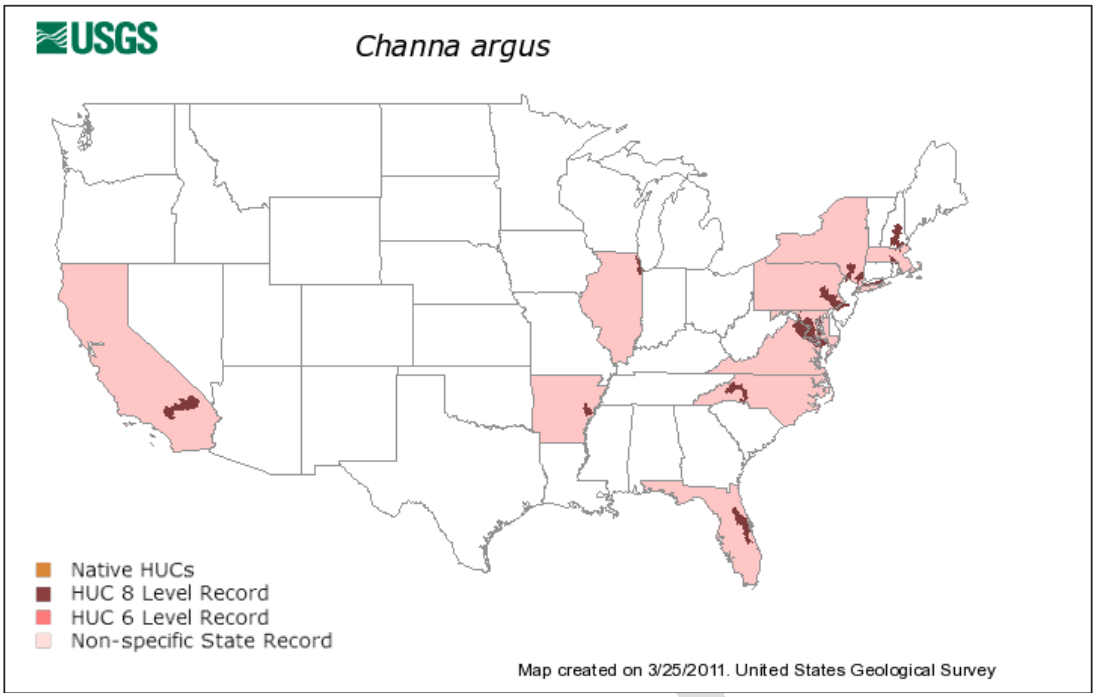


Figure 2. Distribution map of established populations of northern snakehead (in dark red) in the United States. Image from USGS Nonindigenous Aquatic Species website: http://nas.er.usgs.gov/queries/FactSheet.asp?speciesID=2265#imagemap

In Florida, two individuals were caught in St. Johns River below Lake Harney, Seminole and Volusia Counties in 2000, with unconfirmed reports of an additional three individuals caught nearby. Reproduction and establishment in this area has not been confirmed. The fish may have been intentionally introduced from the live-food fish trade to establish a local source of fish (Courtenay and Williams, 2004). A live northern snakehead was purchased in a live-fish food market in Orlando, Florida, in March 2002, even though possession of the species in that state was illegal.

There have been numerous captures of single snakeheads throughout the U.S. that appear to be releases of individual fish but there is no indication of a reproducing population. In areas where reproducing populations have been detected, their rapid population growth makes them easy to detect.

In Maryland, an 18-19 inch northern snakehead was caught by an angler in a small pond in Crofton in May 2002. The angler took several pictures of the fish and then released it back in the pond. After examining the pictures, the Maryland Department of Natural Resources (MDNR) identified the fish as a species of snakehead. That photo was forwarded to Leo Nico at USGS in Gainesville, Florida. Dr. Nico then forwarded the photo to Dr. Walter Courtenay, who identified the fish as a northern snakehead. On June 30, 2002, another angler caught a 26 inch snakehead from the same pond and dip netted eight juvenile snakeheads on July 7 and 8. MDNR personnel then captured more than 100 young-of-the-year snakeheads by electrofishing the pond, which were positively identified as northern snakehead. The pond was treated with rotenone in September

2002, to eradicate the established population of northern snakeheads in the pond. During the eradication effort, over 1,200 snakeheads were recovered. MDNR police were able to determine the source of the introduction. A local resident admitted to the release of two 305 mm. to 355 mm. fish sometime during 2000. He claimed to have purchased the fish at a live food fish market in New York.

In North Carolina, two anglers reported that they caught two northern snakeheads from Lake Wylie, a reservoir of the Catawba River, in July 2002. In August 2002, North Carolina Wildlife Resources Commission personnel sampled the lake by electrofishing but failed to find any snakeheads (Courtenay and Williams, 2004).

In 2004, northern snakeheads of multiple year classes were collected within a 23-km reach of the main-stem tidal freshwater Potomac River in Virginia and Maryland downstream of Washington, D.C. indicating a self-sustaining population. Genetic analysis of a subset of fish from 2004 suggested that most were offspring of either a single pair of breeding adults or multiple female siblings that had been deliberately or unintentionally released (Orrell and Weigt, 2005). Ten of the original 20 fish collected during 2004 were collected from Dogue Creek, and multiple collections occurred in adjacent creeks both to the north and south of Dogue Creek suggesting that the northern snakeheads may have originated from this area. As of the end of 2010, the population has expanded rapidly and inhabits the mainstem and all tributaries of the Potomac River from Great Falls down to the river's mouth (Figure 3). While northern snakeheads are occasionally found in the mainstem of the Potomac River, they are more abundant in shallower water tributaries.

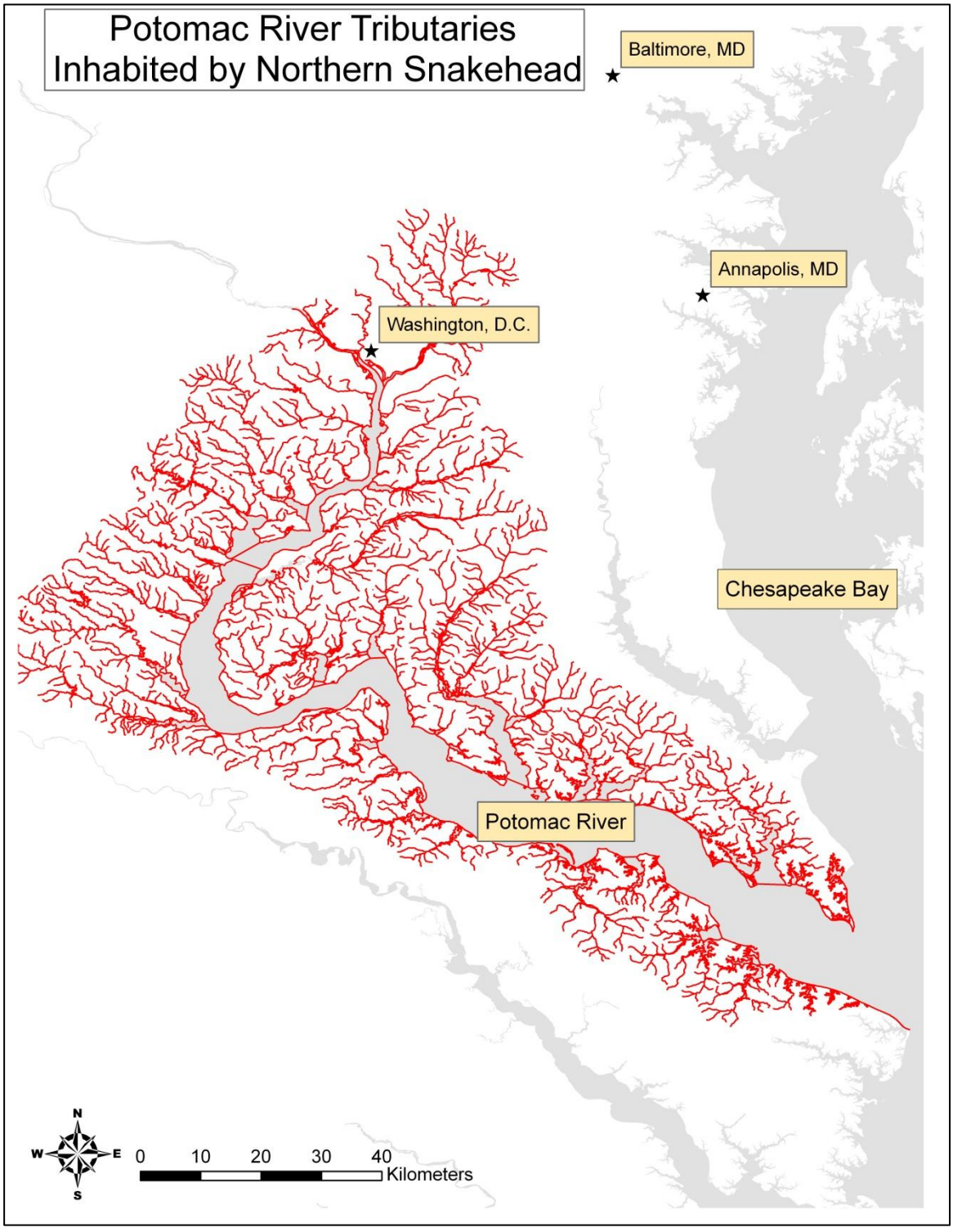


Figure 3. Map of Potomac River tributaries where northern snakeheads have been found (highlighted in red) (USFWS, Maryland Fishery Resources Office).

In July 2004, an angler caught and preserved two snakeheads from a 17-acre lake in Pennsylvania. The fish were later identified as northern snakeheads and a total of six northern snakeheads were captured from the lake. In 2005, sampling efforts resulted in the capture of different-sized snakeheads, including juveniles (personal communication, Richard Horwitz, Pennsylvania Academy of Natural Sciences). Meadow Lake is part of a maze of interconnected embayments and tidal sloughs. Given the openness of the system, Pennsylvania Fish and Boat Commission (PRBC) biologists concluded that the fish had probably accessed adjoining waters of the nearby lower Schuylkill and Delaware Rivers. As a result, PRBC biologists decided that they would monitor the pond and surrounding waters but would not attempt to eradicate the species (PRBC press release, July 23, 2004). There have been confirmed reports of snakeheads escaping from the ponds into the Schuylkill River and Delaware River however the status of the introduction is unknown.

In 2005, four northern snakeheads were found in two ponds in Queens, NY. These ponds seem to have an established population of northern snakehead, but should not allow northern snakehead infiltration to other waterways. More northern snakeheads were found in 2008 in Ridgebury Lake, part of the Wallkill River drainage, a tributary to the Hudson River. In August 2008, Ridgebury Lake, Catlin Creek and adjacent ponds downstream were treated with rotenone. Of the dead northern snakehead collected (>200 individuals), almost all were juveniles, suggesting northern snakeheads were successfully reproducing in the watershed. Eradication was not successful. During summer 2009, two adult northern snakeheads were caught in Valentine Pond, downstream from Ridgebury Lake. The current status of this population is unknown.

Northern snakehead were being cultured on three fish farms in Arkansas until importation, culture, sale, and possession of snakeheads was prohibited by the Arkansas Game and Fish Commission (AGFC) in August 2002 (Courtenay and Williams, 2004). However, in 2008 the AGFC discovered northern snakehead in Piney Creek watershed, a tributary to the Mississippi River. These were likely fish that escaped farm ponds. An attempt to eradicate the Piney Creek population was called "Operation Mongoose" and rotenone was used on 50,000 acres of the watershed to kill the northern snakehead. The watershed was resampled after the eradication attempt and many live northern snakehead were found. Currently, northern snakeheads still inhabit the Piney Creek watershed, and have even been found outside of the watershed. Future work with northern snakehead in Arkansas will include eDNA testing to test for the presence of northern snakehead in nearby watersheds (L. Holt, AGFC, personal comm.).

In April 2011 a large northern snakehead was collected by Delaware Department of Natural Resources biologists in Broad Creek near Laurel, DE during an electrofishing survey. The fish was found in shallow waters at the mouth of the stream coming from Horseys Pond (map). Subsequent sampling in Broad Creek and in Horseys Pond did not find more snakeheads. It is not known if this indicates another population or if it is an isolated incident.

4. Regulation of Northern Snakehead in the U.S.

Prior to the discovery of an established population of northern snakehead in Crofton, Maryland, at least 14 states prohibited possession of all live snakehead species (Table 3).

Table 3. States prohibiting snakeheads prior to July 2002 (from Courtenay and Williams, 2004).

Alabama	Idaho
Arizona	Mississippi
California	Nevada
Colorado	Oregon
Florida	Texas
Kentucky	Utah
Georgia	Washington

Since July 2002, the states of Arkansas, Connecticut, Illinois, Indiana, Kansas, North Carolina, Rhode Island, Pennsylvania, South Carolina, Tennessee, New York, and Virginia have made possession of all live species of snakeheads illegal. Maryland banned northern and blotched snakeheads (*C. maculata*) in late 2004 (Code of Maryland, section 0802.1901), and in 2005 Delaware also banned northern and blotched snakehead. Northern snakeheads have also been banned in the states of Minnesota and Nebraska. In 2009, MDDNR altered their regulation on snakeheads to provide guidance to recreational anglers wanting to harvest northern snakehead. Regulation 08.02.11.04 reads:

> (1) Notwithstanding Natural Resources Article §4-710(g), an individual may capture and possess a snakehead fish using any legal method provided that the head of the snakehead fish is immediately removed, the body is gutted, the gill arches are removed from both sides of the fish or the fish is filleted upon capture.
> (2) The capture and possession of snakehead fish is not subject to any season, creel limit or size limit.
> (3) Further restrictions on possession of certain species of snakehead fish may be found in COMAR 08.02.19.06.

In October 2002, the USFWS listed 28 species of snakeheads, including the northern snakehead, as injurious wildlife under the Lacey Act (18 U.S.C. 42). That listing prohibits the importation and interstate transportation of the 28 snakehead species. However, because the Lacey Act is a federal law, it does not regulate intrastate possession, transportation, or sale within a state where such activities are not prohibited by state law as long as the source did not cross state boundaries or had been imported into the country illegally. Maximum criminal penalties under the Lacey Act are 5 years in prison and a $250,000 fine for an individual and a $500,000 fine for an organization. The USFWS also has import declaration requirements under 14 CFR 14.61, which requires among other things that wildlife listed as injurious must be declared to the USFWS when imported.

5. Potential for Spread in U.S. waters

The possible primary pathway for introduction of the northern snakehead is through the live fish food trade. Introduction into an aquatic system could be from an intentional or unintentional release. Although the listing of northern snakehead and other snakehead

species under the Lacey Act has prohibited importation and interstate transport since October 4, 2002, several live snakeheads were seized by USFWS Agents and Inspection New York as recently as February 2010. In this case, live northern snakeheads were smuggled into the country to supply a live fish food market. The availability of live northern snakeheads could potentially increase the probability of introductions to create a localized source of live fish for the live-food fish market (Courtenay and Williams, 2004).

Prayer release also has been identified as a potential pathway for introduction of northern snakeheads. In eastern Asia, some people believe that one can accrue merits by freeing captive animals into the wild as a form of prayer to the gods. When organized by temples, normally a large number of animals are involved and are referred to as "ceremonial animal releases". In Taiwan, researchers found that 29.5% of the people of all religions participate in prayer animal releases. Ceremonial animal release is also practiced in Malaysia, Thailand, Cambodia, Vietnam, Hong Kong, and Korea (Severinghaus and Chi, 1999).

In the Potomac River, where northern snakeheads are established, there is concern that interest in developing fisheries for snakeheads could increase the potential for introductions into other waterways. Because this species is an obligate air breather, it is easily transported alive out of water as long as it is kept moist (Courtenay and Williams, 2004). The northern snakehead has a wider latitudinal range and temperature tolerance than other snakehead species, which indicates that it could become established throughout most of the contiguous United States and some waters in adjoining Canadian provinces (Courtenay and Williams, 2004; Herborg et al., 2007). The most probable source of spread would be by humans considering that larger species of snakeheads are popular with anglers in several locations within their native and introduced ranges (Courtenay and Williams, 2004) or that markets exist creating demand for them. This concern is increased by the fact that it appears only a small number of fish were released in the Crofton pond and Potomac River introductions.

Mitochondrial sequence variation was examined in northern snakeheads taken from the Potomac River tributaries; Crofton Pond in Maryland; Pine Lake in Wheaton, Maryland; Newton Pond in Massachusetts; and FDR Park in Philadelphia, Pennsylvania. There were seven unique haplotypes in the 29 specimens studied, with no haplotype shared between areas of introduction. This indicates that there were several separate introductions of northern snakeheads into these waters, and that no two introductions came from the same source. In the Potomac River (an established population), one haplotype was shared by all of the fish less than 480 mm TL, indicating that these fish are the offspring of either a single breeding pair or the offspring from multiple adult female siblings (Orrell and Weigt, 2005).

6. Eradication and Control Efforts for Northern Snakehead

The potential for eradication of northern snakehead depends on the aquatic system in which they are found. This species was successfully eradicated from a small storm water pond in Crofton, Maryland with the use of rotenone, and by dewatering by a pump at

Pine Lake in Wheaton. Eradication will be nearly impossible and control efforts challenging in large lakes or riverine systems such as the Potomac River, where northern snakeheads become established. Control in smaller systems depends on the amount of vegetation, access to the water body, and effectiveness of available control methods. When a population is discovered, it is typically too late for eradication unless the population is isolated. Options for control include the use of piscicides such as rotenone and electrofishing. Rotenone works by preventing fish from removing oxygen from the water. However, chemical control using rotenone and other similar toxins would likely be ineffective to air-breathing snakeheads and damaging to non-target organisms except in closed situations. Electrofishing and netting may provide some level of control but would not result in eradication of a population because the gears are not effective at capturing all size and age classes (USFWS, 2002). Demographic models have shown that removal of northern snakehead should occur during pre-spawn periods or prior to juvenile dispersal in order to be the most efficient in limiting population growth (Jiao et al. 2009). This is also the time period when northern snakehead are more easily captured by electrofishing due to limited movement of adults (Lapointe et al. 2010). More specifically, snakeheads appear to be most active during peak daylight times, so targeted removal should occur during late morning/early evening hours when fish are less active (Fig. 5; USFWS, unpub. data).

7. Ecological Impacts

There is little information in the scientific literature about effects of northern snakeheads on other aquatic organisms. The predatory nature of northern snakeheads indicates that their introduction would likely affect other populations of fish, amphibians, and invertebrates through direct predation, competition for food resources, and alteration of food webs (Courtenay and Williams, 2004). Through predation, ecosystem balance could be modified drastically if northern snakeheads became established in waters with low diversity of native fishes and low abundance or absence of native predatory species.

Establishment of northern snakeheads could have an adverse effect on endangered and threatened species in the system. Of all the taxa listed as endangered and threatened in U.S. aquatic habitats, 16 amphibians, 115 fishes, and 5 of the 21 crustaceans (surface-dwelling crayfish and shrimp), would be the most likely affected (Courtenay and Williams, 2004). Based on habitat requirements and life history, fishes are more likely to be affected by introduced northern snakeheads than amphibians and surface-dwelling crustaceans. However, the addition of a voracious predator in the aquatic community with any listed amphibian or crustacean would constitute a threat (Courtenay and Williams, 2004).

In the western United States, habitats of listed fishes range from steep-gradient, coldwater mountain streams, lower-gradient large desert rivers, to thermal springs in desert areas. Eastern fishes occupy a variety of habitats, including springs, creeks, large rivers, and the Great Lakes (USFWS, 2002). Due to a wide tolerance of temperature and habitats, northern snakeheads would be capable of living in any of the above habitats. Since northern snakeheads are predatory, all of the fishes listed as endangered or threatened would be vulnerable to predation at some stage in their life history. The degree of threat

would vary from high in small, isolated habitats, such as desert thermal springs and their outflows in the American southwest, to somewhat less in steep-gradient coldwater mountain streams. The likelihood that one or more species could be in danger of extinction or become endangered within the foreseeable future after introduction of northern snakeheads is high. That risk could differ depending on the system. For example, introduction of just a few northern snakeheads could reduce or eliminate a fish or crustacean species confined to a small section of stream or isolated spring habitat. Alternatively, a small number of northern snakeheads introduced but not established in a stream or lake would likely have less of an impact. However, the establishment of northern snakeheads in any system could represent a significant threat to a listed species (USFWS, 2002).

Potential to transfer pathogens to native organisms is largely unknown. However, like most+ other fishes, northern snakeheads can be hosts to a suite of parasites (Table 4). Chiba et al. (1989), cited by Courtenay and Williams (2004), reported that northern snakeheads introduced parasites to Japan, but the parasite species introduced were not listed in the report. Jinhui (1991), cited by Courtenay and Williams (2004), listed parasitic crustaceans of northern snakeheads from Chinese waters. Courtenay and Williams (2004) reviewed the literature and could not find any parasites of snakehead species that they believed indicated a potential threat to native North American fishes, but stated that the potential had not been examined. Snakehead species under intensive culture such as *Channa striata* and *Channa punctata* are susceptible to epizootic ulcerative syndrome (EUS), which causes high mortality. EUS may have originated in India in the 1980s, but has also been found in Pakistan, Thailand, and the Philippines, with outbreaks reported from all these areas in the 1990s. *Channa striata* has been identified as being the intermediate host for a parasitic disease that can affect humans caused by a helminth parasite, *Gnathostoma spinigerum*. Between 1985 and 1988, there were 800 suspected cases of Gnathostomiasis in Bangkok (Setasuban, 1991; cited by Courtenay and Williams, 2004). It is unknown whether the northern snakehead may serve as an intermediate host for larvae of this parasite (Courtenay and Williams, 2004).

Nematodes were observed in northern snakehead captured from the Potomac River. The USFWS has been working with researchers in Japan to try to get a positive identification. The Japanese researchers believe that the nematode is an eustrongylides, native to US waters, and that the snakeheads are probably infected by feeding on soft-rayed fish like mummichog and killifish carrying the parasite.

Table 4. Parasites of northern snakeheads (Adapted from Courtenay and Williams, 2004 and Bykhovskaya-Pavlovskaya and others, 1964).

Parasite	Group	Host Tissues	Other Fishes Affected
Myxidium ophiocephali	Myxosporidia	gallbladders, liver ducts	
Zschokkella ophiocephalli	Myxosporidia	kidney tubules	
Neomyxobolus ophiocephalus	Myxosporidia	gill filaments	
Mysosoma acuta	Myxosporidia	gill filaments	crucian carp
Myxobolus cheisini	Myxosporidia	gill filaments	
Henneguya zschokkei?	Myxosporidia	gills, subcutaneous, musculature	salmonids (tubercle disease of salmonids)
Henneguya ophiocephali	Myxosporidia	gill arches, suprabranchial chambers	
Henneguya vovki	Myxosporidia	body cavity	
Thelohanellus catlae	Myxosporidia	kidneys	
Gyrodactylus ophiocephali	Monogenoidea	fins	
Polyonchobothrium ophiocephalina	Cestoidea	intestine	
Cysticercus gryporhynchus cheilancristrotus	Cestoidea	gallbladder, intestine	Cyprinids, perches
Azygia hwangtsiui	Trematoda	intestine	
Clinostomum complanatum	Trematoda	body cavity	perches
Pingis sinensis	Nematoda	intestine	
Paracanthocephalus curtus	Acanthocephala	intestine	Cyprinids, esocids, sleepers, bagrid catfishes
Paracanthocephalus tenuirostris	Acanthocephala	intestine	
Lamproglena chinensis	Copepoda	gills	

8. Economic Impacts

The northern snakehead's native range (24-53°N) and water temperature tolerance (0-31°C) indicates a species that, if introduced, could establish feral populations throughout most of the United States (Courtenay and Williams, 2004; Herborg et al., 2007). The northern snakehead could potentially compete with commercially and recreationally important fish species through predation and competition for food and habitat in ponds, streams, canals, reservoirs, lakes, and rivers. In the Potomac River, northern snakeheads appear to have similar habitat and feeding preferences as recreationally important species

such as the largemouth bass (*Micropterus salmoides*). Analysis of stomach contents of northern snakeheads collected in the Potomac River included white perch (*Morone americana*), a recreationally and commercially important fish species caught in the Chesapeake Bay, and killifish, an important prey for both white and yellow perch (Odenkirk and Owens, 2005). It is difficult to predict what economic impact the northern snakehead would have on Potomac River recreational and commercial fishing industries, but it could prove to be substantially detrimental over time.

Costs associated with control or eradication efforts of northern snakehead are high. Eradication of northern snakeheads from a small pond in Crofton, Maryland was estimated to cost $110,000. Eradication efforts in Arkansas were estimated to be $750,000 in direct costs to treat 400 miles of creeks and ditches in the Piney Creek watershed. Costs were incurred from personnel time, convening and conducting two meetings of the Maryland Snakehead Scientific Advisory Panel, application of herbicides and rotenone, and disposing of dead fish. Costs of eradication efforts in larger water bodies would be greater. Eradication from an open system such as the Potomac River may be impossible and control efforts would be fiscally and physically challenging (Courtenay and Williams, 2004). Costs in responding to ongoing reports from the public also are significant (personal communication, Don Cosden, Maryland Department of Natural Resources).

9. Current Research Underway

In 2006, Lapointe et al. (2010) radio-tagged adult northern snakehead in Virginia tributaries of the Potomac to determine seasonal habitat selection. They found snakeheads in the Potomac tributaries generally preferred shallow habitats that provided cover. During the post-spawn period, from September to November, snakeheads were found in offshore habitats with vegetative (Eurasian milfoil and hydrilla) cover. However, during winter snakeheads preferred offshore habitats with deep water. In the pre-spawn period (spring), snakeheads moved upstream within their respective tributaries and remained there throughout the spawning period. During the spawning season snakeheads almost exclusively chose habitats along the shoreline that provided macrophytic cover for spawning (Lapointe et al. 2010).

Creel surveys along the Potomac River tributaries were done in 2008 and 2009. In 2008 creel surveys were only done in Virginia tributaries by VDGIF, while in 2009 creel surveys were done in Maryland and Virginia tributaries (VDGIF and USFWS). Creel surveys can provide managers with data regarding how often recreational anglers catch northern snakehead, as well as examine catch rates of species that may be negatively impacted by the presence of northern snakehead (i.e., largemouth bass). Catch rates of northern snakehead more than doubled from 2008 to 2009, even though catch rates were extremely low for both years (0.0025 and 0.0057 snakehead per angler hour, respectively). Largemouth bass catch rate was approximately one fish per angler hour for each year. This shows that anglers are more commonly encountering northern snakehead while fishing on the Potomac River, and at least suggests that the population could be

expanding and/or growing. Creel surveys should continue every 2-3 years to monitor recreational catch rates of northern snakehead and other species.

As of 2011, it appears that northern snakehead and largemouth bass only have moderate resource overlap in the Potomac River, perhaps limiting the extent that northern snakehead will negatively impact the largemouth bass population. However, juveniles of both species had greater resource overlap than adults. Using ecological forecast models in conjunction with current knowledge, when adult snakeheads were removed from the system, there was a noticeable increase in biomass of largemouth bass. The highest increase in largemouth bass biomass occurred when northern snakehead removal rates were between 25 and 50 times higher than normal (Love et al., in prep).

In spring 2009, a cooperative tagging program for northern snakehead began on the Potomac River. The cooperative tagging program is a partnership of state and federal agencies, including the District of Columbia Department of the Environment's Fisheries and Wildlife Division, Maryland Department of Natural Resources (MDDNR), VDGIF, and USFWS. In this program, northern snakehead are tagged with an external tag and released where they were captured. Tagged fish are consequently captured and killed by recreational anglers, and the tag is reported to USFWS. These tag returns provide essential information on northern snakehead distribution and movement within the Potomac River.

By April 2011, over 1,133 northern snakeheads have been tagged in the Potomac River (Fig. 4). Of these tagged fish, 96 have been recaptured by both state or federal agencies and recreational anglers. The majority of recaptured northern snakehead (approximately 90%) remained in the creeks where they were initially tagged. This suggests that many individuals in the population do not move far distances. However, those individuals that did move outside the creek they were initially tagged in were capable of moving relatively large distances. One tagged fish was captured approximately a year after it was tagged, and had moved 47 river kilometers upstream. Most northern snakehead movement appears to be during the pre-spawning months of April and May and associated with high flow events (unpubl. data, USFWS).

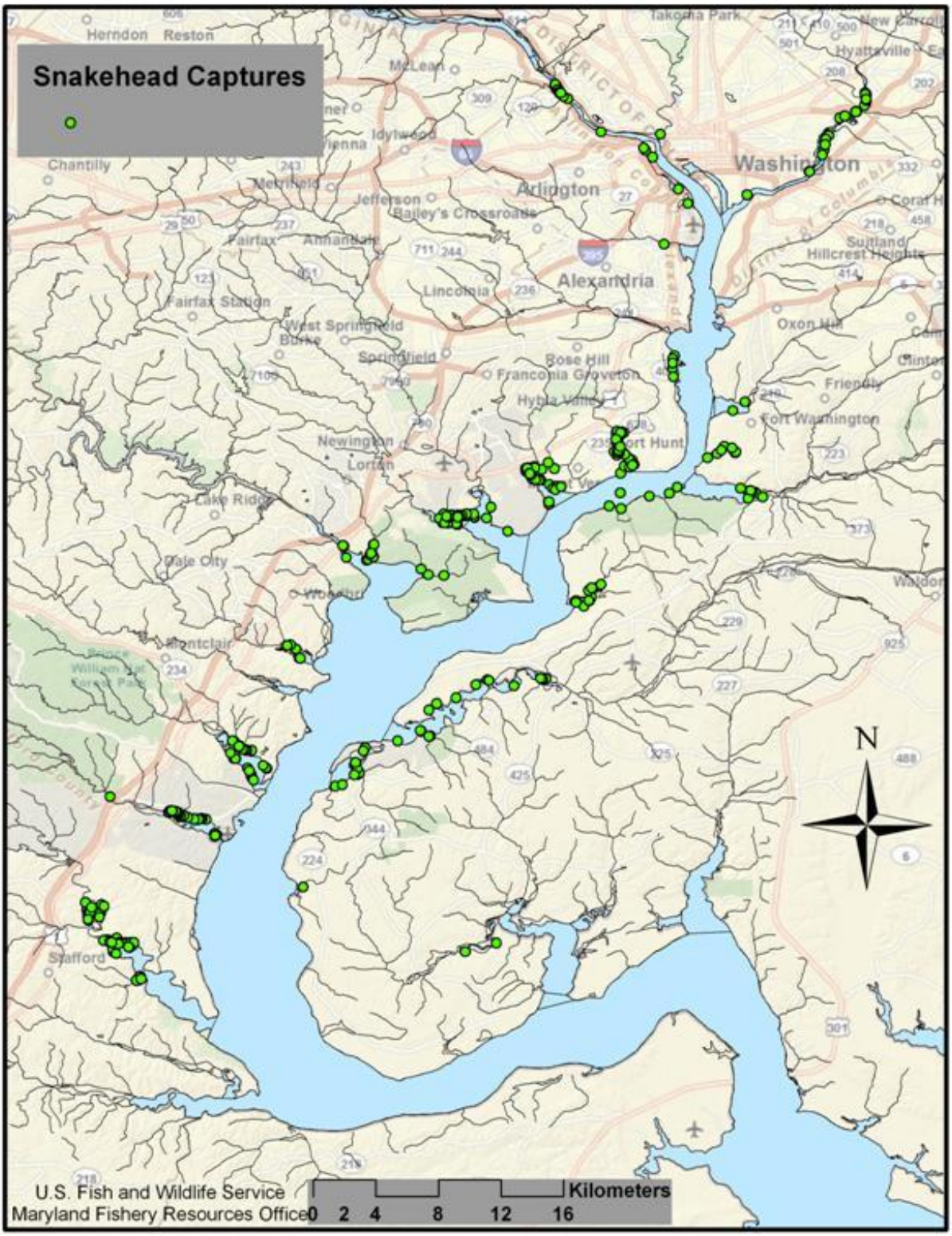


Figure 4. Capture locations of tagged northern snakeheads along the Potomac River as of February 2011.

External tagging of northern snakehead on the Potomac River will continue in 2011. Tag return models can provide estimates of abundance for tributaries along the Potomac. These estimates will aid in observing population trends of northern snakehead. Furthermore, tag returns could show the potential expansion of northern snakehead into new habitats and also help identify potential habitats that could be at risk to invasion by northern snakeheads.

In 2010-11, USFWS continued radio tracking work in Chopawamsic Creek, a tributary to the Potomac River. Twelve mature northern snakeheads had radio tags implanted into their body cavity. These radio tags are capable of identifying when fish actively swim and supply a unique code for each individual fish. Three stationary, autonomous receivers were set up along the northern shoreline of Chopawamsic Creek to monitor northern snakehead movement within the creek. These receivers provided coverage over a significant portion of the creek. In addition to stationary receivers, manual tracking was done from a boat to provide additional monitoring.

Motion sensors in the radio tags provided essential information on snakehead behavior throughout the year. Seasonal and climatic events appear to drive northern snakehead behavior. Northern snakehead activity tended to peak within two to five days after periods of high rainfall. Furthermore, as temperatures dropped during fall and winter, so too did snakehead activity. Northern snakeheads appear to be most active during daylight hours (Fig. 5). Snakeheads may be more active during the day because they are actively hunting prey. Research planned for 2011 will attempt to better explain these patterns of snakehead movement.

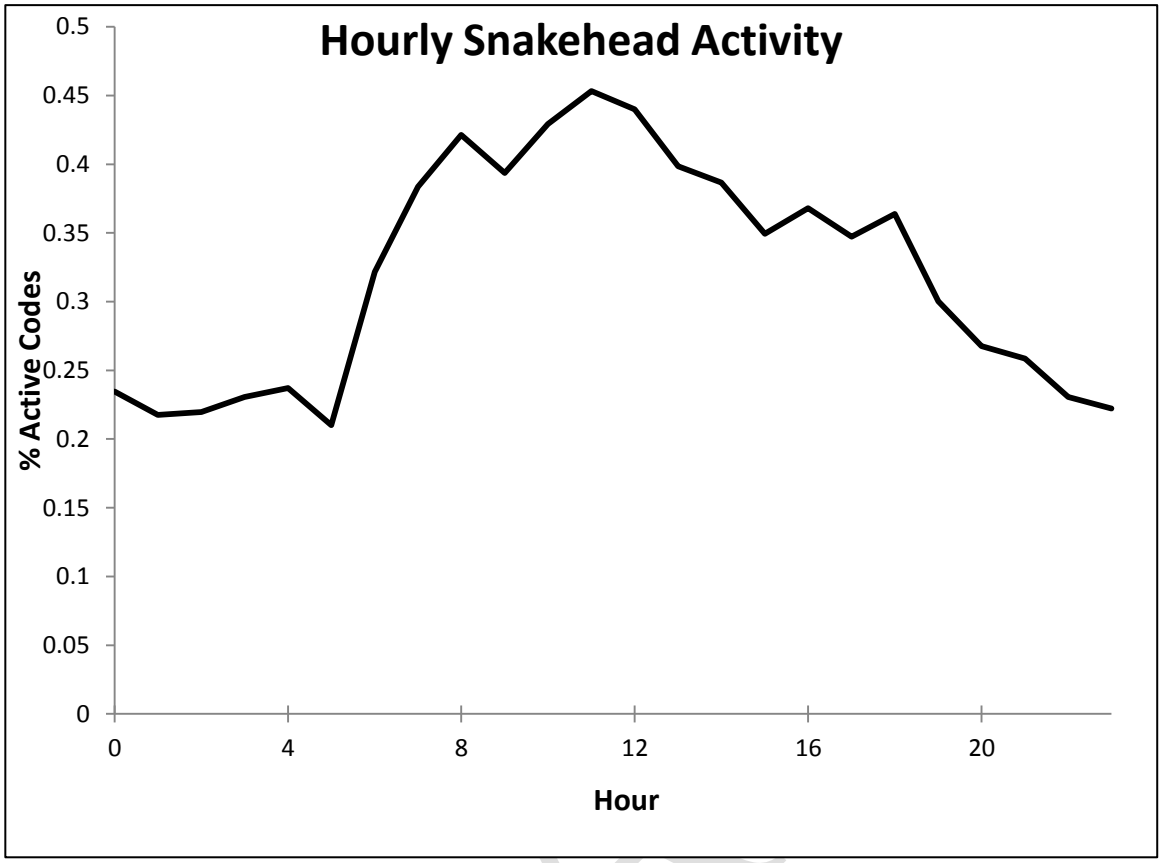


Figure 5. Activity levels (recorded active codes divided by total codes recorded) of 12 radio-tagged adult northern snakehead located in Chopawamsic Creek, Potomac River, Virginia.

9. Primary Priorities for Implementation

Primary Priority Action Items	
Objective	**Item**
Objective 1. Prevention **Objective 1. Prevention (cont.)**	1.1) Work with states, the District of Columbia, and jurisdictions to promulgate regulations or statutes that would prohibit possession, transportation, sale, acquisition, and introduction of all snakehead species. 1.2) Promote the enactment of clear, effective, consistent, and enforceable regulations and statutes among bordering or shared jurisdictions. 1.3) Recommend that states authorize substantial penalties for violating those statutes. 1.4) Consider all the vectors by which northern snakeheads can be introduced or spread into new areas. 1.5) Assess the risk of introduction through each identified vector. 1.6) Identify management, outreach, and enforcement options available to reduce the risks associated with each identified vector. 1.7) Obtain information on life history and biology of the northern snakehead in its native environment and in U.S. waters to better predict where the species could become established. 1.8) Through genetic analysis determine source regions of established populations. 1.9) Develop approaches to prevent importation from source regions.
Objective 2. Early Detection and Rapid Response	2.1) Develop an information system via the web or protocol to notify other jurisdictions of sightings of northern snakehead. 2.2) Identify legal barriers in jurisdictions that would prevent rapid response efforts from occurring. 2.3) Enact legislation in jurisdictions that allow the appropriate agency access on public/private property and inter-jurisdictional waters to assess a potential introduction, implement control methods, or eradicate northern snakehead. 2.4) Recommend that jurisdictions develop a rapid response plan for northern snakehead. 2.5) For those jurisdictions that have developed plans, obligate funding or identify sources of funding for rapid response. 2.6) Develop containment guidelines for infested areas to prevent spread. 2.7) Identify trained and knowledgeable individuals to respond to new introductions of northern snakehead in jurisdictions. 2.8) Incorporate monitoring for northern snakehead into other, existing aquatic surveys in jurisdictions.

Objective 3. Eradication	3.1) Compile a list of existing control options for eradication. 3.2) Conduct research to determine additional control strategies for eradication. 3.3) Evaluate ecological and economic impacts of eradication.
Objective 4. Long-term Management	4.1) Determine ecological and economic impacts of control methods on other species. 4.2) Determine effectiveness of control options in different systems. 4.3) Conduct studies to understand life history traits, biology, and behavior to inform long-term control options.
Objective 5. Research **Objective 5. Research (cont.)**	5.1) Conduct studies with northern snakehead in closed systems to better understand life history traits, biology, and behavior to determine impact at the ecosystem and species level and to inform long-term control options. 5.2) Determine baseline histology of northern snakehead to better understand the risk of this species spreading parasites and disease to native organisms. 5.3) Determine methods for aging and sexing northern snakehead to better understand biology and life history traits. 5.4) Evaluate the effectiveness of different field collection techniques for northern snakehead. 5.5) Translate literature on northern snakeheads published in countries where the species is either native or naturalized.
Objective 6. Outreach	6.1) Develop outreach tools for target groups to reduce risks associated with each identified pathway. 6.2) Develop a press kit for jurisdictions to utilize for rapid response and containment of new introductions. 6.3) Develop outreach materials in each jurisdiction to educate the public on identification of northern snakehead and who to contact to report sightings. 6.4) Train state and federal wildlife officers, U.S. Customs and Border Protection Inspectors on how to identify live juvenile and adult northern snakehead. 6.5) Coordinate outreach efforts with those for other non-native fish species in order to provide greater effectiveness in preventing future introductions of new species**.**
Objective 7. Review and Assess Progress	8.1) Annually review progress with implementation of actions in the management plan. 8.2) Incorporate information associated with implementation of actions in the plan into the national clearinghouse.

Objective 1. Prevent new introductions of northern snakehead within the U.S. and control the spread of established populations into new areas.

1.1. Work with states, the District of Columbia, and jurisdictions to promulgate regulations or statutes that would prohibit possession, transportation, sale, acquisition, and introduction of all snakehead species.

Justification—Working Group members identified this as an issue because some states prohibit possession of only those snakehead species that could become established in their waters. As long as the source of the snakeheads was not through interstate or foreign commerce, the Lacey Act does not prohibit possession of live snakeheads if states do not have regulations to prohibit their possession. Without state law prohibiting possession of live snakeheads, wildlife law enforcement officers would find it difficult to prove a violation of state or federal law. Even though certain species of snakeheads may not be capable of reproducing in the wild in certain climates in the United States, they could be transported to another state where a viable reproducing population could be established if introduced.

1.2. Promote the enactment of clear, effective, consistent, and enforceable regulations and statutes among bordering or shared jurisdictions.

Each jurisdiction in the Potomac River drainage should have the same regulations to prevent further spread or introduction of northern snakehead into new areas. Each jurisdiction should prohibit possession of live northern snakehead.

1.3. Recommend that states enact appropriate criminal and civil penalties for illegal acts that serve as a deterrent.

Justification--Working group members cited the importance of states enacting criminal and civil penalties to deter individuals from introducing snakehead species into new areas.

1.4. Consider all the vectors by which northern snakehead can be introduced or spread into new areas.

Justification--Working group members identified the live food fish market as potentially the main vector for introduction of northern snakehead into areas. Prayer animal release was also mentioned as a possible vector for introduction of snakehead species. Northern snakeheads were possibly introduced to the Potomac River to establish a local source for this fish species. Anglers fishing for northern snakehead in the Potomac could also introduce the fish in new areas.

1.5. Assess the risk of introduction through each identified pathway.

Assessing the risk of introduction associated with each identified pathway will assist states and jurisdictions in prioritizing enforcement and outreach efforts to prevent additional introductions of northern snakehead.

1.6. Identify management, outreach, and enforcement options available to reduce the risks associated with each identified pathway.

1.7. Obtain information on life history and biology of northern snakehead in its native environment and in U.S. waters to better predict where it could become established.

An extensive literature review has already been conducted by Courtenay and Williams (2004) but some of the working group members have been able to obtain additional literature in Japanese, Chinese, and Korean on northern snakeheads. This literature will have to be translated in English to provide information on life history and biology of northern snakehead in its native range.

1.8. Through genetic analysis determine source regions of established populations.

A Working Group member stated that to do this analysis, one would need to know the genetic makeup of all of the other populations of snakehead worldwide. This would provide information for agencies involved in inspections and enforcement at ports of entry to determine which countries are importing these fish illegally.

1.9. Develop approaches to prevent importation from source regions.

Determine which agencies are involved in inspecting shipments of imported live aquatic organisms at ports of entry and make sure they are aware of the laws pertaining to import of live snakehead species. Determine other means of importing live northern snakehead, such as purchase through websites or hobbyist groups.

Objective 2.0. Detect and rapidly respond to northern snakehead introductions in U.S. waters.

2.1. Develop an information system via the web or protocol to notify other jurisdictions of sightings of northern snakehead.

Justification--Working Group members cited the importance of notifying bordering or shared jurisdictions when a northern snakehead is found. The use of a notification system via the web was suggested as an effective mechanism for prompt notification.

2.2. Identify legal barriers in jurisdictions that would prevent rapid response efforts from occurring.

Justification--Working Group members cited lack of access to private property to control or eradicate northern snakehead as a major example of a legal barrier that would prevent rapid response efforts from occurring. All potential legal barriers to rapid response occurring in a timely manner should be identified and solutions should be provided.

2.3. Enact legislation in jurisdictions that allow the appropriate agency access on public/private property and inter-jurisdictional waters to assess a potential introduction, implement control methods, or eradicate a snakehead species.

There is legislation in Virginia that authorizes the Department of Game and Inland Fisheries to suppress or eradicate any nuisance species populations and gives the Department authority to obtain a warrant to conduct such operations on private property. In Maryland, there is legislation that authorizes the Maryland Department of Natural Resources to enter and inspect property to determine if a "state of nuisance" exists, and establishes provisions related to abatement. Legislation was prompted in both of these states due to legal access issues that agency personnel were confronted with when trying to initiate rapid response on private property.

2.4. Recommend that jurisdictions develop a rapid response plan for northern snakehead.

A rapid response plan would examine and address factors that may result in a delay in eradication efforts such as acquiring the proper permits for different control methods, establishment of safety protocol for the different control methods, a plan to deal with the media, a plan for containment, identification of the agency and personnel that would be contacted if a northern snakehead is found.

2.5. For those jurisdictions that have developed plans, identify funding mechanisms for rapid response of northern snakehead.

States at high risk for introduction of northern snakehead should obligate or identify sources of funding for rapid response.

2.6. Develop containment guidelines for infested areas to prevent spread.

In areas where eradication is possible, containment guidelines should be developed based on the type of aquatic system in which introduction has occurred. These guidelines should be incorporated into the rapid response plan.

2.7. Identify trained and knowledgeable individuals to respond to new introductions of northern snakehead in jurisdictions.

Justification--Working Group members cited the need to identify trained and knowledgeable individuals to respond to new introductions. This could consist of a directory of agency personnel and scientists that can identify the fish species, and recommend containment, eradication, and control options. This directory could be posted on a central website that contains information on northern snakehead.

2.8. Incorporate monitoring for northern snakehead into other, existing aquatic surveys in jurisdictions.

Monitoring programs for northern snakehead should be established in states where they have been introduced or could become introduced. Monitoring for the fish should occur even if it is incorporated into existing monitoring or survey efforts for other species.

Objective 3. Wherever possible, contain and eradicate newly discovered populations of northern snakehead.

3.1. Compile a list of existing control options for eradication.

A list of different control options should be developed for northern snakehead in a range of environments in which this species could be introduced. The effectiveness and feasibility of different control options in different systems should be evaluated. For example, piscicides wouldn't be able to be used in a reservoir that is a drinking water source. The list should be developed in part with input from members of the NSWG. As information on eradication strategies develops the eradication list should be periodically updated.

3.2. Conduct research to determine additional control strategies for eradication.

At this time, control options are extremely limited for northern snakehead. It is important that new control options are developed and tested for effectiveness in different aquatic systems.

3.3. Evaluate ecological and economic impacts of eradication.

Ecological and economic impacts of eradication must be considered for different aquatic systems. For example, it may not be economically or ecologically beneficial to use piscicides in a large, open aquatic system.

Objective 4. Provide long-term adaptive management and mitigate impacts of northern snakehead in U.S. waters where eradication is not possible.

4.1. Determine ecological and economic impacts of control methods on other species.

Evaluate ecological risks and benefits to native flora and fauna and economic costs and benefits to determine which control strategies should be employed for long term management.

4.2. Determine effectiveness of control options for long term management in different systems.

Conduct research to determine effectiveness of different control options for long term management in different systems.

4.3. Conduct studies to understand life history traits, biology, and behavior to inform long-term control options.

Biotelemetry and tagging studies in the Potomac River are needed to examine spatial and temporal distribution. Information on spawning and feeding behavior are also needed to inform long term control options.

4.4. To prevent further introductions, continue effective law enforcement to discontinue supply routes, sources, and markets.

As we gain more knowledge about the risk of different pathways, it is important that the natural resource managers communicate with law enforcement to effectively prevent new introductions from occurring and prevent spread of established populations into new areas.

Objective 5. Conduct research to understand impacts of northern snakehead on native aquatic organisms.

Snakeheads have not been methodically studied in their native habitat. Very little is known about the potential impacts of snakehead introductions in the United States. Information concerning the biology, behavior, movement and stock dynamics of this fish are needed to determine impacts. This information would also serve to suggest control and management measures to reduce impacts. Studies on snakeheads populations in the Potomac River would provide information on abundance, growth, prey preference, parasite loads, salinity tolerance and habitat use.

5.1. Conduct studies with northern snakehead in closed systems to understand life history traits, biology, and behavior to determine impact at the ecosystem and species level and to inform long-term control options.

Justification--Working group members discussed the importance of having a better understanding of the biology and life history traits of this species in its introduced range. Also, ecological impacts on other species are largely unknown at this time. Carefully controlled studies in a contained aquatic system (e.g., isolated pond) could contribute to a

better understanding of this species that could inform long term control and eradication options.

5.2. Determine baseline histology of northern snakehead to better understand the risk of this species spreading parasites and disease to native organisms.

Justification--Very little is known about diseases and parasites of northern snakehead in its native range. Working Group members cited the importance of determining baseline histology of this species so we can better determine whether the organisms carry introduced parasites or pathogens that could potentially affect native species.

5.3. Determine methods for aging and sexing northern snakehead to better understand population dynamics.

Justification--Natural resource managers in the Potomac River have had a difficult time determining the sex of non gravid northern snakeheads they have captured. Otolith interpretation for aging also has been difficult, especially with the absence of known-age comparative specimens.

5.4. Evaluate the effectiveness of different field collection techniques for northern snakehead.

In the Potomac River, it has been difficult for natural resource managers to assess the effectiveness of different field collection techniques because they are still unsure where the fish are temporally and spatially. Once that information is gathered, we can more readily assess the effectiveness of different field collection techniques.

5.5. Translate literature on northern snakeheads published in countries where the species is either native or naturalized.

Information on northern snakehead in its native range will help us to understand its biology and life history traits which in turn will help us predict potential ecological and economic impacts and inform long term control and eradication options.

5.6. Conduct a symposium to compile and publish scientific information pertaining to snakehead.

A symposium with published proceedings would be an efficient means for effectively communicating and cataloging research results in a timely manner to natural resource managers throughout the country. A national symposium sponsored by the American Fisheries Society would be one possible venue.

Objective 6. Develop outreach tools to prevent new introductions of northern snakehead within the U.S. and control the spread of established populations into new areas.

6.1. Develop outreach tools for target groups to reduce risks associated with each identified pathway including information on regulations and penalties for possession and introduction.

Justification--Working Group members discussed utilizing the media (newspapers, radio stations, website) to effectively communicate what penalties are associated with introduction, transport, and live possession of northern snakehead. In the Potomac River, jurisdictions should create a poster or brochure that focuses on stewardship, health issues, and regulations and penalties associated with live possession of northern snakehead. This poster or brochure could be in several different languages. The jurisdictions could target boat ramps, fishing license holders, cultural festivals, and bait and tackle shops. Working Group members also cited the need for a liaison for communicating with ethnic communities that may consume or utilize northern snakehead. Stewardship could be emphasized by citing examples where the introductions of other species have had high costs to communities and ecosystems.

6.2. Develop a press kit for jurisdictions to use for rapid response and containment of new introductions.

One of the most important components of rapid response is communication with the public. Each jurisdiction should have one point of contact for the press to ensure a correct and consistent message. Contact information and other general information about northern snakehead could be developed and posted on the National Northern Snakehead website (Action Item 7.1).

6.3. Develop outreach materials in each jurisdiction to educate the public on identification of northern snakehead and who to contact to report sightings.

Outreach materials created to assist the public with identification of northern snakehead should be developed in a simple, effective way so that the public can easily identify northern snakehead from other similar looking species. These materials could be posted on the National Northern Snakehead website (Action Item 7.1).

6.4. Train state and federal wildlife officers, U.S. Customs and Border Protection Inspectors on species identification of all live juvenile and adult northern snakehead.

Education programs and materials should be developed to inform inspection agents and state and federal wildlife officers about identification of live juvenile and adult northern snakehead, applicable law, and high risk sources. Educational programs and materials should be regularly updated if regulatory status changes or new pathways are identified.

6.5. Coordinate outreach efforts with those for other non-native fish species in order to provide greater effectiveness in preventing future introductions of new species.

Create outreach materials that focus specifically on introduction through specific pathways to prevent future introductions of other new species.

Objective 7. Review and assess progress of the national management plan.

7.1. Annually review progress with implementation of actions in the management plan.

The working group members should meet on an annual basis to review progress of implementation of management actions identified in the plan, to prioritize actions, and to discuss potential funding sources.

7.2. Incorporate information associated with implementation of actions in the plan into the National Northern Snakehead website.

Information associated with implementation of management actions should be incorporated in the website in a timely manner.

Literature Cited

An asterisk (*) after the citation indicates that the reference was not seen by the authors or was cited from other references.

Atkinson, C.E. 1977. People's Republic of China, in Brown, E.E. ed., World Fish Farming: Cultivation and Economics: Westport, Connecticut, AVI Publishing Co., p. 321-344.*

Baltz, D.M. 1991. Introduced fishes in marine systems and inland seas: Biological Conservation, v. 56, p. 151-177.*

Balzer, T., Balzer, P., and Pon, S. 2002. Traditional use and availability of aquatic biodiversity in rice-based ecosystems. I. Kampong Thom Province, Kingdom of Cambodia: Rome, Italy, FAO/Netherlands Partnership Programme "Awareness of Agriculture Biodiversity."*

Berg, L.S. 1947. Classification of fishes both recent and fossil: Ann Arbor, Michigan, J.W. Edwards, 517 p. *

Berg, L.S. 1965. Freshwater fishes of the USSR and adjacent countries, Vol III (4th ed., improved and augmented): [Translated from Russian; original 1949, Jerusalem, Israel Program for Scientific Transactions], p.937-1381.

Bykhovskaya-Pavlovskaya, I.E., Gusev, A.V., Dubinina, M.N., Izyumova, N.A., Smirnova, T.S., Sokolovskaya, I.L., Shtein, G.G., Shil'man, S.S., and Epshtein, V.M. 1964. Key to parasites of freshwater fish of the USSR: Isreal Program for Scientific Translation, Jerusalem, 919 p.*

Chiba, K., Yasuhiko, T., Sakai, K., and Oozeki, Y. 1989. Present status of aquatic organisms introduced into Japan, *in* De Silva, S.S. (ed.), Exotic organisms in Asia-Proceedings of the Workshop on Introduction of Exotic Aquatic Organisms in Asia: Manila, Philippines, Asian Fisheries Society Special Publication 3, p. 63-70. *

Courtenay, W.R., Jr., and J.D. Williams. 2004. Snakeheads (Pisces: Channidae): A biological synopsis and risk assessment. U.S Geological Survey Circular 1251, 143 p.

Dukravets, G.M. and Machulin, A.I. 1978. The morphology and ecology of the Amur snakehead, *Ophiocephalus argus warpachowskii*, acclimatized in the Syr Dar'ya basin: Journal of Ichthyology, v.18, no. 2, p. 203-208.*

Dukravets, G.M. 1992. The Amur snakehead, *Channa argus warpachowskii*, in the Talas and Chu River drainages: Journal of Ichthyology, v. 31, no. 5, p. 147-151.*

Food and Agriculture Organization of the United States. 1994. Aquaculture production 1986-1992 (4th ed.): Rome, Italy, FAO Fisheries Circular 815, 216 p.*

Frank, S. 1970. Acclimatization experiments with Amur snakehead, Ophiocephalus argus warparchowskii (Berg, 1909) in Czechoslavakia: Vstník eskoslovenské Spolenosti Zoologické, v. 34, p. 277-283.*

Guseva, L.N. and Zholdasova, I.M. 1986. Morphoecological characteristics of the snakehead (*Ophiocephalus argus warpachowskii*) (Berg) as an introduced species in water bodies of the lower delta of the Amu Dar'ya, in Biological Resources of the Aral Region, FAN, Tashkent, p. 98-134.*

Hartel, K.E., Halliwell, D.B., and Launer, A.E. 2002. Inland Fishes of Massachusetts: Lincoln, Massachusetts, Massachusetts Audobon Society, 328 p.*

Jiao, Y., N.W.R. Lapointe, P.L. Angermeier, and B.R. Murphy. 2009. Hierarchical demographic approaches for assessing invasion dynamics of non-indigenous species: An example using northern snakehead (*Channa argus*). Ecological Modelling, v.220, p.1681-1689.

Herborg, L., N.E. Mandrak, B.C. Cudmore, and H.J. MacIsaac. 2007. Comparative distribution and invasion risk of snakehead (Channidae) and Asian carp (Cyprinidae) species in North America. Canadian Journal of Fisheries and Aquatic Sciences 64: 1723-1735.

Jinhui, Kuang Puren Qian. 1991. Economic fauna of China: Editorial Committee, Fauna Sinica, Academic Sinica: Beijing, China, Science Press, 203 p.*

Lapointe, N.W.R., J.T. Thorson, and P.L. Angermeier. 2010. Seasonal meso- and microhabitat selection by the northern snakehead (*Channa argus*) in the Potomac river system. Ecology of Freshwater Fish, v.19, p. 566-577.

Liu, J., Cui, Y., and Liu, J. 1998. Food consumption and growth of two piscivorous fishes, the mandarin fish and the Chinese snakehead. Journal of Fish Biology, v. 53, p. 1071-1083.*

Love, J.W., J.J. Newhard, and I. Park. 2011. Impact of Northern Snakehead *Channa argus* harvest on Biomass of Largemouth Bass *Micropterus salmoides*: An ecosystem management approach for tidal fresh reaches of the Potomac River drainage (U.S.A.). in prep.

Maryland Department of Natural Resources. 2002. Snakehead Scientific Advisory Panel first report to the Maryland Secretary of Natural Resources. http://www.dnr.state.md.us/irc/ssap_report.html

Nikol'skiy, G.V. 1956. Ryby basseyna Amura [Fishes of the Amur Basin]: Moscow, USSR Academy of Sciences. [In Russian]*

Odenkirk, J. and S. Owens. 2005. Northern snakeheads in the tidal Potomac River system. Transactions of the American Fisheries Society 134: 1605-1609.

Odenkirk, J. and S. Owens. 2007. Expansion of a Northern snakehead population in the Potomac river system. Transactions of the American Fisheries Society 136: 1633-1639.

Okada, Y. 1960. Studies of freshwater fishes in Japan, II, Special part: Prefectural University of Mie, Journal of the Faculty of Fisheries, v. 4, no. 3, p-1-860, 61 plates.*

Orrell, T.M., and L. Weigt. 2005. The northern snakehead *Channa argus* (Anabantomorpha: Channidae), a nonindigenous fish species in the Potomac River, U.S.A. Proceedings of the Biological Society of Washington 118(2): 407-415.

Pennsylvania Fish and Boat Commission Press Release. July 23, 2004. Another exotic species confirmed in Pennsylvania waters. http://sites.state.pa.us/PA_Exec/Fish_Boat/newsreleases/2004/snakehead.htm

Setasuban, P., Nuamtanong, S. Rojanakittikoon, V. Yaemput, S., Dekumyoy, P., Akahane, H., and Kojima, S. 1991. Gnathostomiasis in Thailand: A survey of intermediate hosts of Gnathostoma spp. with special reference to a new type of larvae found in Fluta albam in Cross, J.H. (ed.), Emerging problems in food-borne parasitic zoonosis-Impact on Agriculture and Public Health-Proceedings of the 33rd SEAMEO-TROPMED Regional Seminar, Chinag Mai, Thailand, 14-17 November 1990: Supplement to Southeast Asian Journal, p. 220-224.*

Severinghaus, L. and L. Chi. 1999. Prayer animal release in Taiwan. Biological Conservation 89: 301-304.

Sifa, Li and Senlin, Xu. 1995. Culture and capture of fish in Chinese reservoirs: Ottawa, Canada, International Development Research Center, 128 p.*

U.S. Department of the Interior, Fish and Wildlife Service and U.S. Department of Commerce, U.S. Census Bureau. 2001 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.

U.S. Geological Survey Press Release. August 2, 2005. USGS Confirms Snakeheads in NYC Lake-Invasive Fish Species Threatens Native Fauna. http://www.usgs.newsroom/article.asp?ID=852

U.S. Fish and Wildlife Service. 2002. 50 CFR part 16. RIN 1018-AI36. Injurious Wildlife Species; Snakeheads (family Channidae) Proposed Rule. http://www.eswr.com/f072602.txt

U.S. Fish and Wildlife Service. 2011. Brooklyn trading company owner charged with illegally importing live snakehead fish. Press Release April 28, 2011. http://www.fws.gov/northeast/le/snakeheadarrest.html

Wee, Kok Leong. 1982. Snakeheads-Their biology and culture, *in* Muir, J.F. and Roberts, R.J., eds. Recent advances in aquaculture: Boulder, Colorado, Westview Press, p. 180-213.*